Enhancing AIRCRAFT SURVIVABILITY

a Vulnerability Perspective

COMPOSITE STRUCTURE DESIGNS:

LESS VULNERABLE, MORE AFFORDABLE

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Bill Baron
Air Force Research Laboratory
Jamie Childress
Boeing Defense and Space
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Design for Affordability

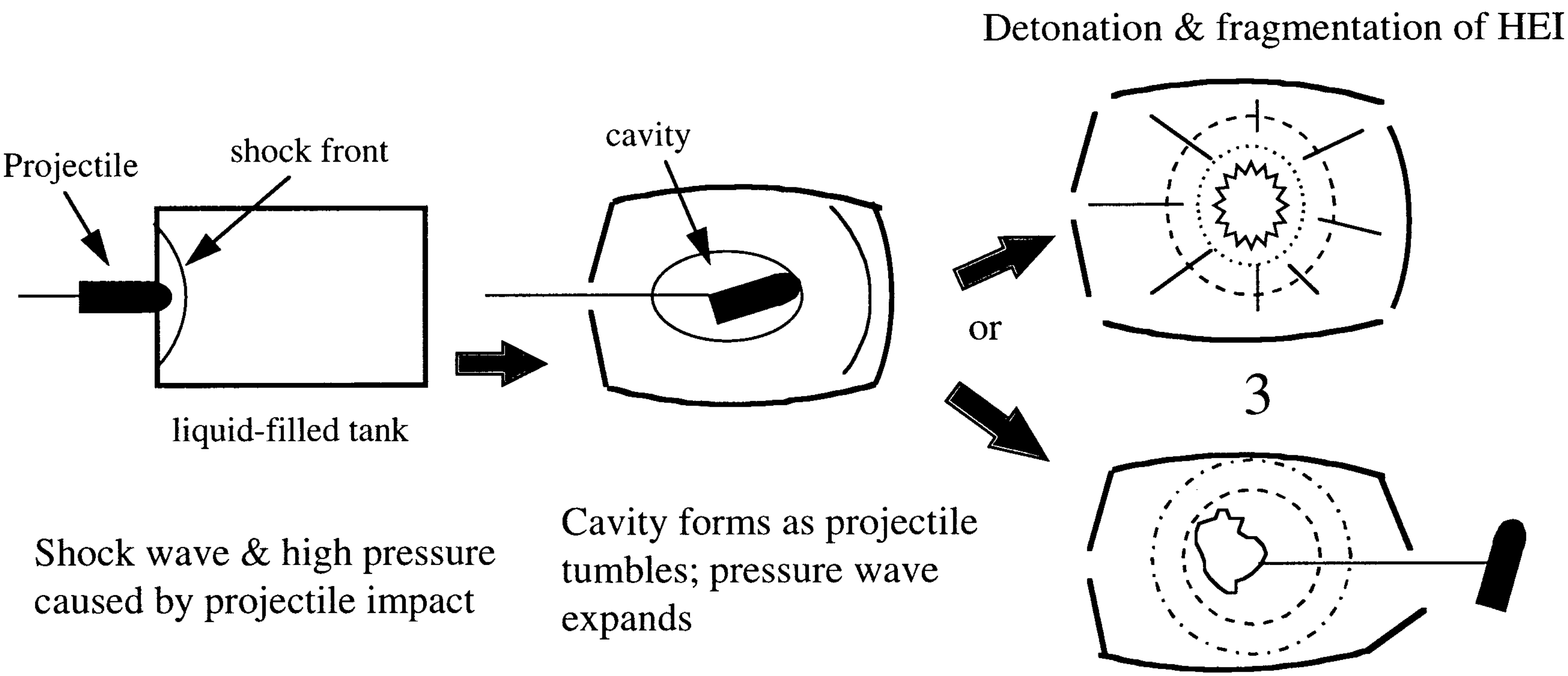
AFFORDABILITY = f {LOW COST + PERFORMANCE}

- Survivability is a key component of performance

- Aircraft Lethality is improved through the development of survivable structure
- Structure is damaged in almost all ballistic events
- Vulnerability must be considered upfront in an aircraft development program
  - Design space is fixed early; limiting future solutions if the design does not meet the Live Fire Law requirements
  - Retrofit of primary structure is not an affordable option
  - Vulnerability reduction features can be exploited efficiently

Hydraulic Ram Threat

Hydraulic Ram is the critical design condition for structure



Shock wave & high pressure caused by projectile impact

1

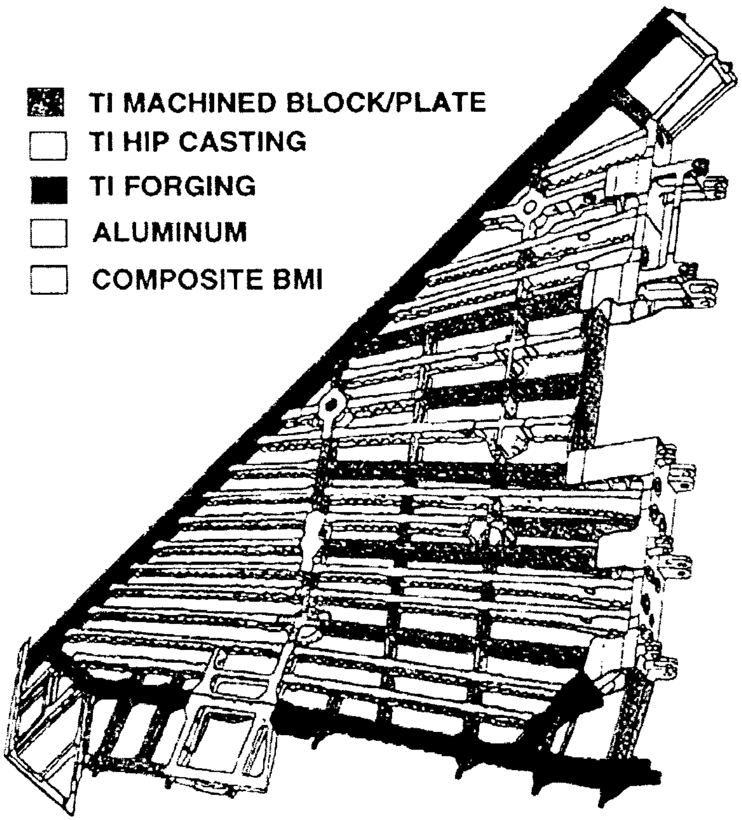
Cavity forms as projectile tumbles; pressure wave expands

2

API exits tank & cavity collapses

Recent Experience

- Titanium spars in F-22 wing required to meet Live Fire requirements
- F-22 Wing Box Total Weight = 3130 lbs per Ship Set
- Increased Weight of Titanium Spars, Additional Fasteners, and Ribs = 120 lbs per Ship Set
- 120/3130 = 4% Weight Increase Due to Hydrodynamic Ram



Increased cost and weight of the survivable structural system

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Survivable Composite Structure

Myth or Reality?

Current Design Practice

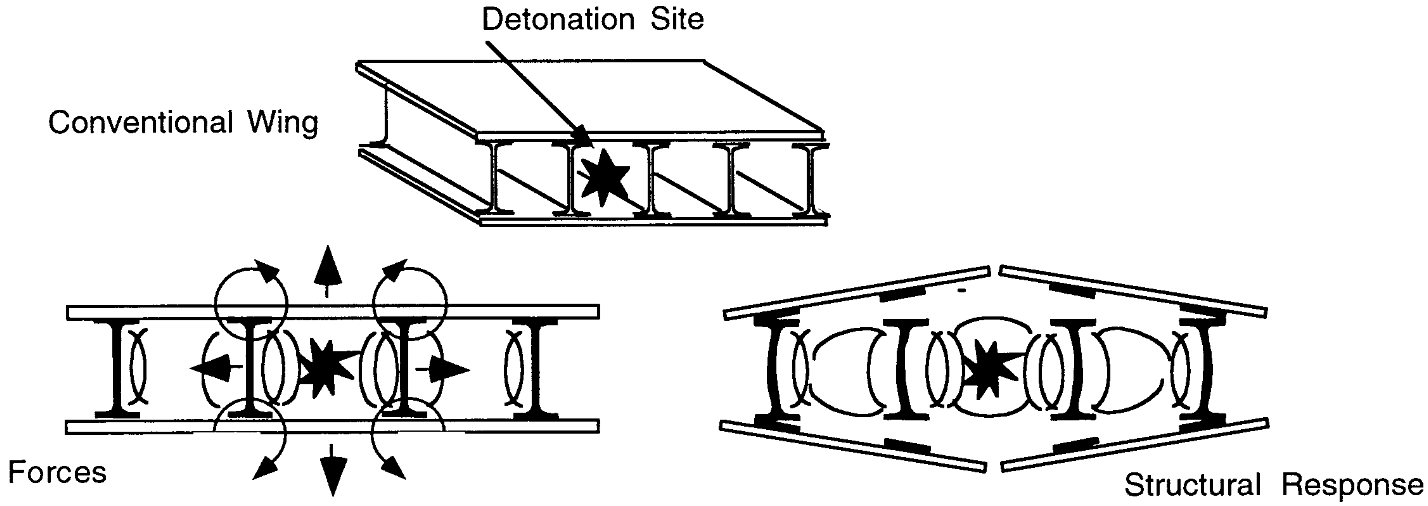
- Apply metallic design approach
- Mechanical fasteners to provide containment
- Use toughened material matrix
- Use parasitic materials to disrupt coupling

COMPOSTIES PERCEIVED TO BE LESS SURVIVABLE

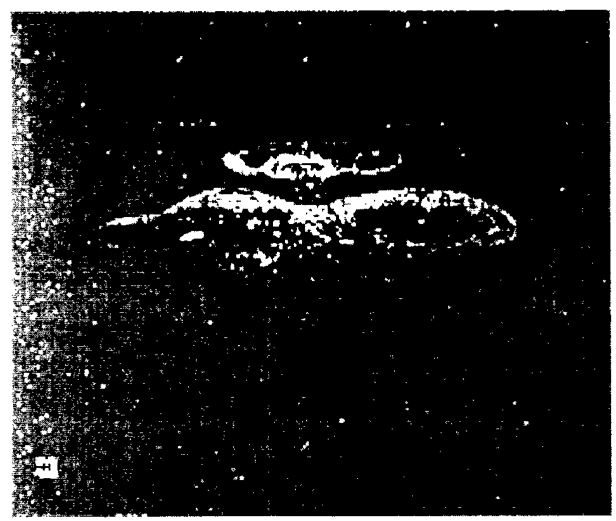
Design for Affordable Composite Structure

- Tailor fiber architecture in unitized designs for robust joints
- React hydraulic ram pressures in the composite fibers
- Establish zones of controlled failure through stiffness tailoring
- Design to establish a pressure impedance mis-match

Conventional Failure Modes

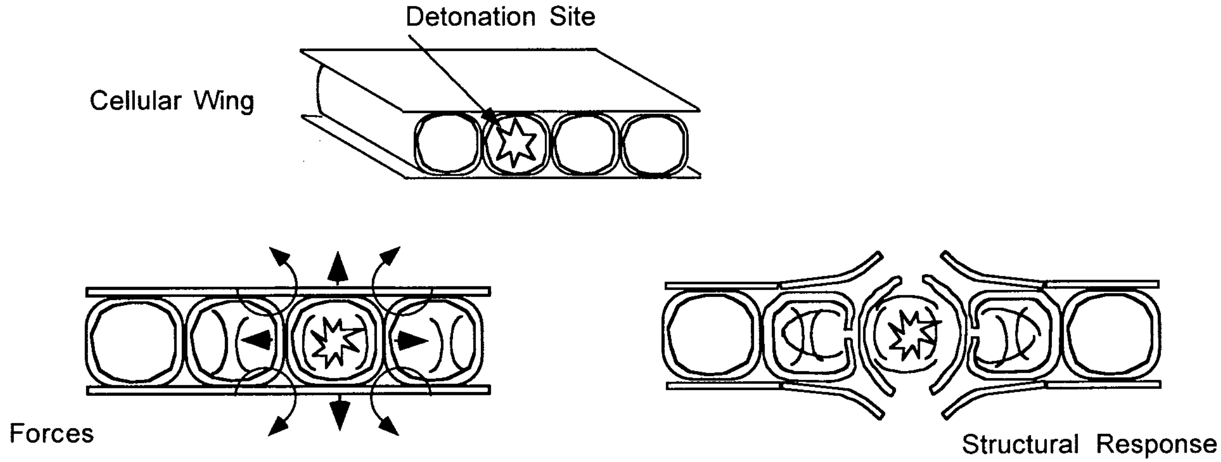


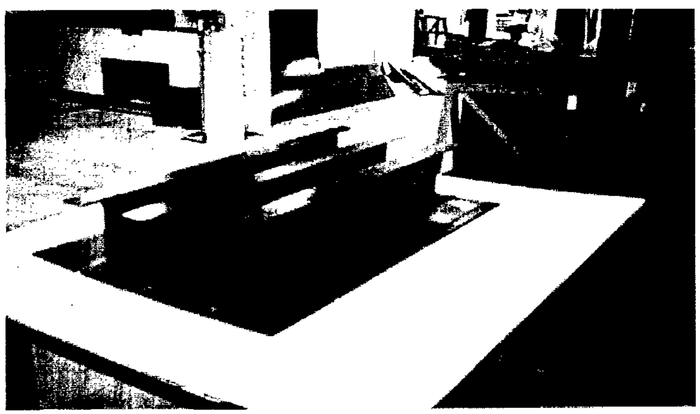
- Joints are the “achilles heel” of the structural system
- Bolt pull-through allows panel separation
- Pressures fully coupled between bays

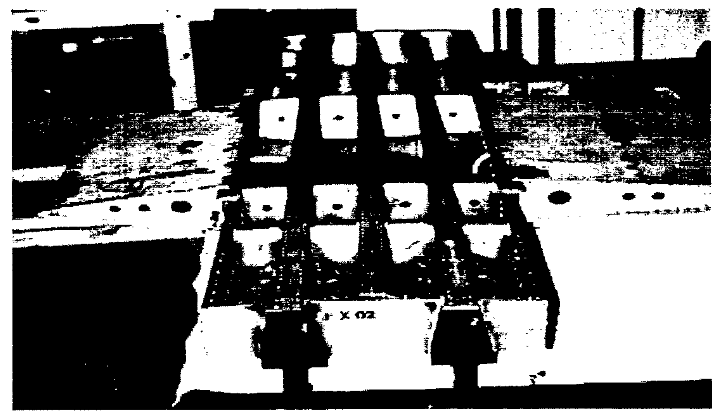


23mm API; Bolted Composite Panel C-Scan

Unitized Composite Design



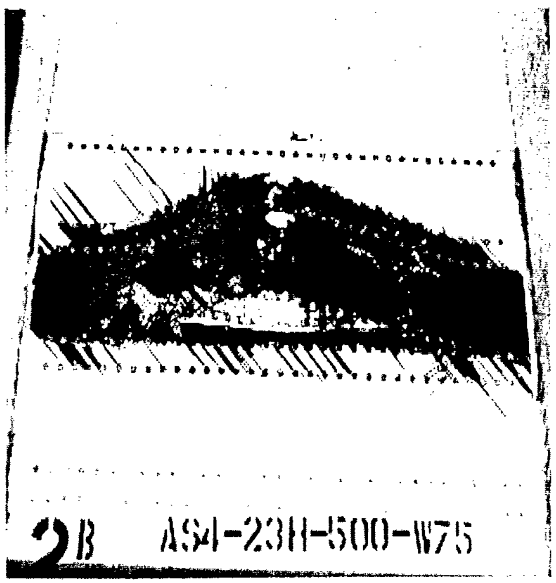




- Web plies wrap around the cell to form the inner moldline
- Testing conducted under fully simulated combat conditions
  - Structural bending load, 23 HEI, Hydraulic Ram & Airflow

Results of Testing
23mm HEI

LOWER COST & LOWER WEIGHT ALL COMPOSITE DESIGN
DEMONSTRATED IMPROVEMENT IN SURVIVABILITY



- CONVENTIONAL BASELINE STRUCTURE
- METALLIC SUBSTRUCTURE & COMPOSITE SKIN
- EXTENSIVE MULTIBAY DAMAGE

- COCURED COMPOSITE DESIGN
- CELLULAR DESIGN CONFIGURATION
- ZPINNED-FASTENERLESS LOWER SKIN
- CONTROLLED MEMBRANE TENSION FAILURE MODE

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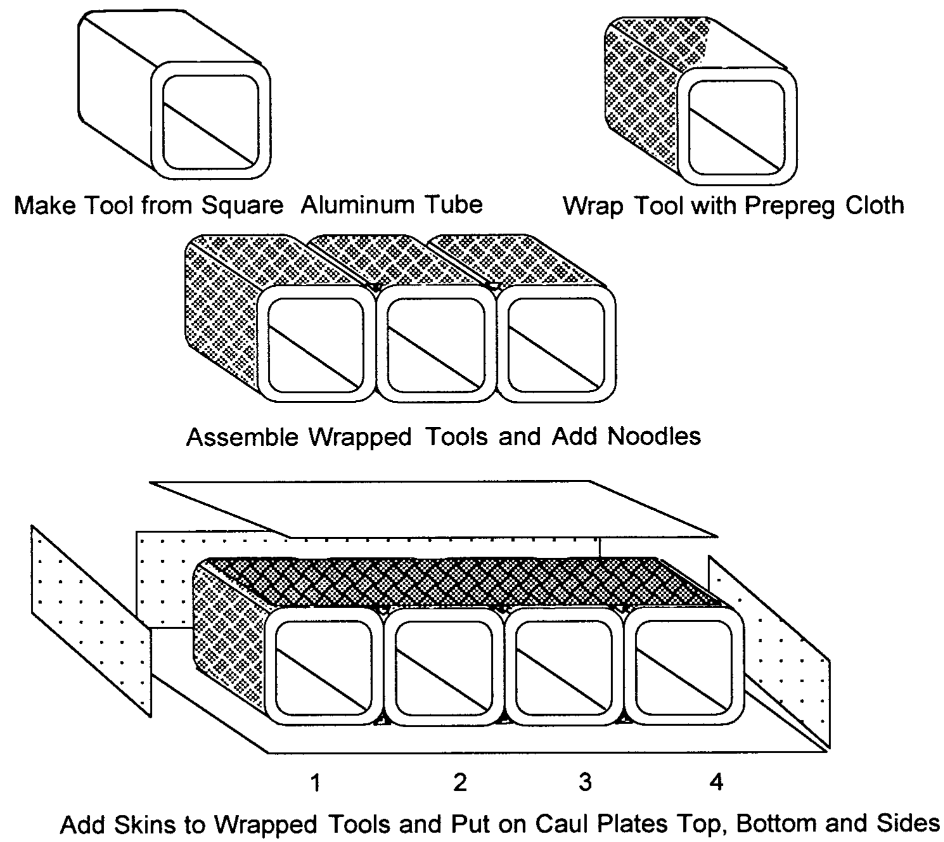
CONCEPT SCALE-UP

- Wrap Composite Fabric Around Cell Tooling
- Assemble Cells
- Apply Skin to Assembly
- Z-Pin "Spars" to Skin (Along Cell Joint Line)
- Ultrasonic Z-Pinning Approximately 5-10X Faster Than Bolting
- Cure Entire Assembly



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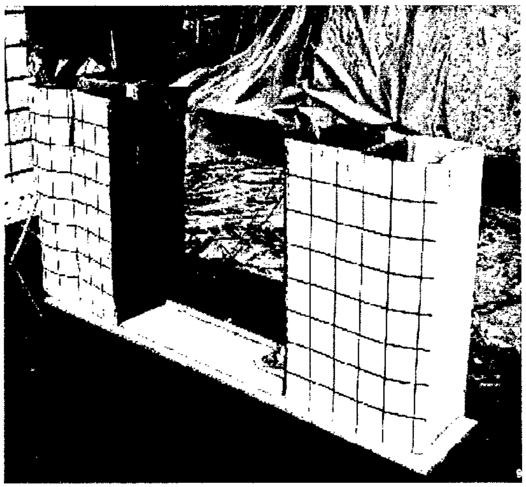
RESULTS OF TESTING



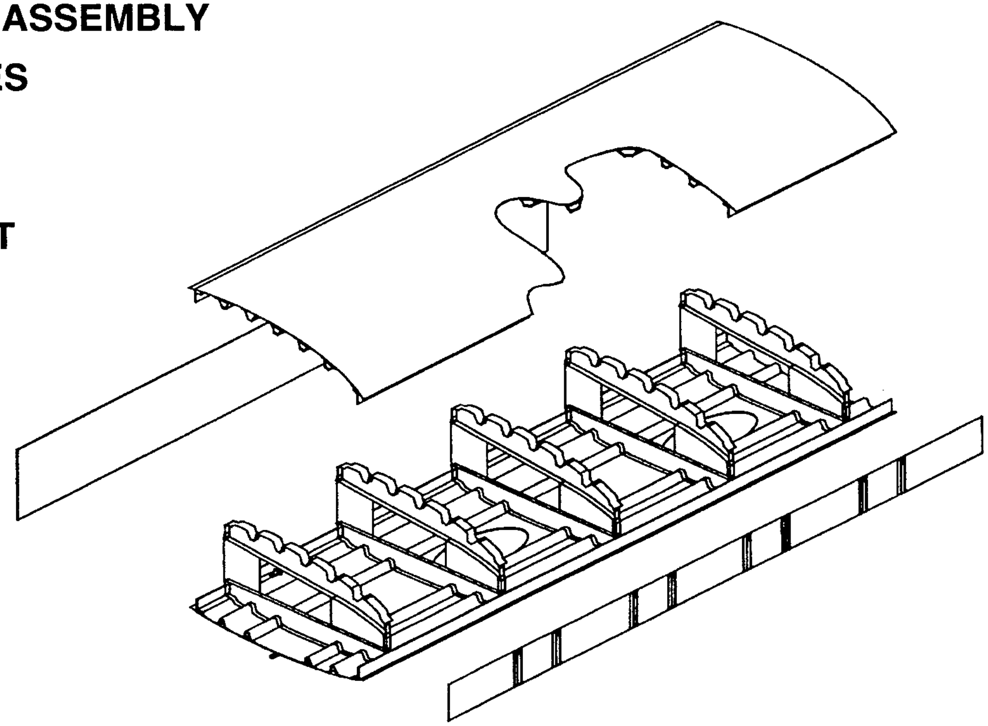
Cellular Box

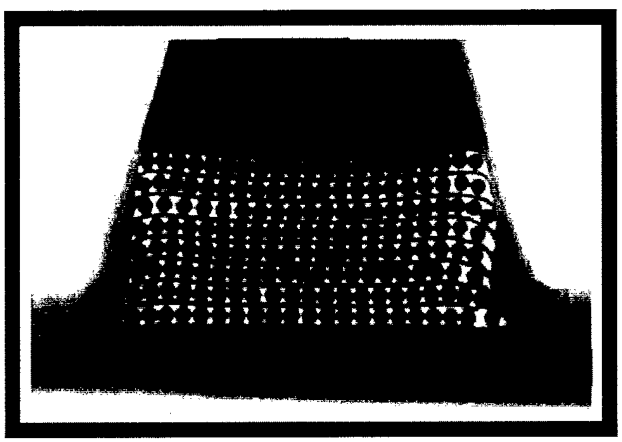
- Muliple tests conducted with 30mm HEI Threat
- Tests conducted with Box Full of Water and with 60%-full decoupled
- Demonstrated Controlled Damage to the impacted and adjacent bays

- Damage dominated by skin failure
- Pressure transmitted through adjacent bays can be significantly reduced through decoupling
- Decoupling allows reflected fluid momentum to vent

DESIGN FOR DEEP-SECTION WING STRUCTURE

- WINGBOX DESIGNEDTO ALLOW SIMPLIFIED ASSEMBLY
- COMPONENT FABRICATION DEMONSTRATES INNOVATIVE LOW COST PROCESSES
  - 50% COST REDUCTION
  - STRONGER, MORE DAMAGE TOLERANT
  - SAME WEIGHT





- TAPE LAYED SKINS WITHINTEGRAL PULTRUDED - ROD REINFORCED HAT STIFFENERS
- ENABLE IMPROVED LOAD PATH MANAGEMENT

INTERLOCKED BONDED RIBS REACT PULLOFF LOADS IN SHEAR

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DEEP SECTION TEST RESULTS

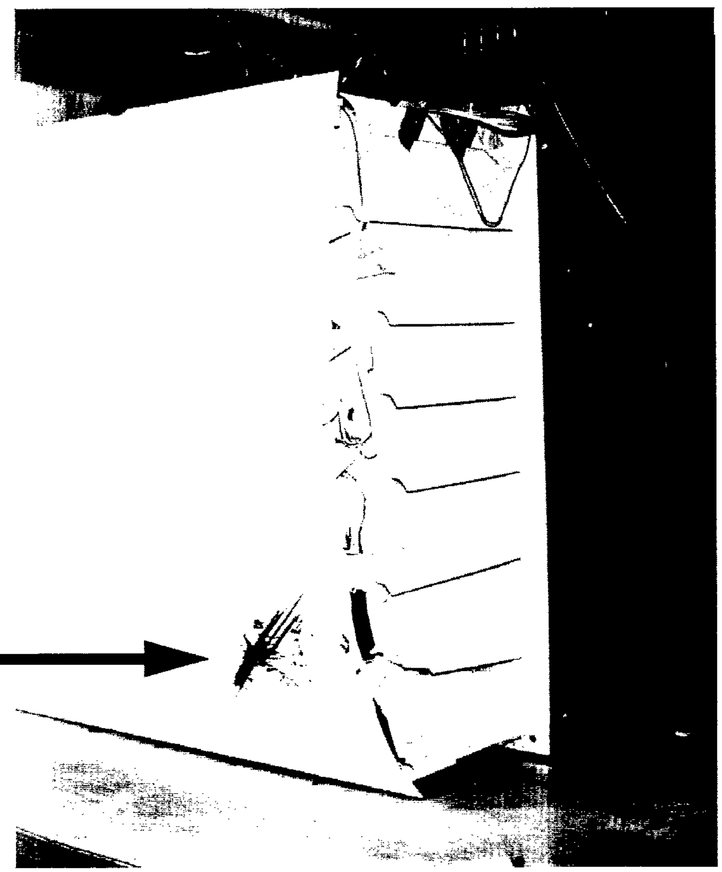
- BONDED CONSTRUCTION *IS SURVIVABLE*
- FASTENER REDUCTION REDUCES COST *DOES NOT* INCREASE VULNERABILITY
- COMBINATION OF PULTRUDED RODS AND SOFT SKINS CONTAINS DAMAGE - LOAD PATHS LARGELY MAINTAINED

FIVE STIFFENER - TWO RIB TEST PANEL RESULTS

23 mm API EXIT DAMAGE

SIMULATED FUEL

HIT ON ROD REINFORCED STIFFENER



LESSONS LEARNED
Keys to Affordable Composite Structure

- Elastic joint behavior, avoid stiff joints like sinewave spars
- Strong joint/weak skin
- Wide spar caps
- Fibers wrap continuous around fuel bay
- Z-Pinned substructure/skin attachment prevents peel
- Provide weak point in skin at desired failure location
- Interlocked bonded structure
- Design structural layout with fuel management for hydraulic ram protection in mind
- Manage loads around damage zones

SURVIVABLE UNITIZED DESIGN COST SAVINGS POTENTIAL

- Designing for Survivability can offer significant cost savings
  - F-22 Wing Set Weight Delta Due to Hydram = +120 lbs 120 lbs x $1000/lb Lifecycle Cost = $120,000
  - F-22 Wing Set Cost Delta Due to Hydram = $220,000
  - Cell Design Eliminates 8,000 Wing Fasteners; 8,000 x $50/ Fastener = $400,000

- Total Savings $120K + $220K + $400K = $740K/Aircraft
- Production of 3000 aircraft; 3000 x740K = $2.22 Billion

CONCLUSIONS

- Conventional designs are not more affordable than "all-composite" design approaches
- Survivability must be traded upfront as a structural requirement in the conceptual/preliminary design stage of development (knowledge gained through early "build & bust")
- Composites provide the designer with strength/stiffness management freedom to control failure characteristics
- Designs must be demonstrated to accommodate multidisciplinary requirements
  - Emerging structural design concepts (e.g. stitching, zpinning, interlocked bonding, textiles)
  - Advanced manufacturing(e.g. ebeam, RTM, material placement)
  - Subsystems integration